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Study on sustainable development of rural household energy in northern China

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Abstract

The status of rural household energy consumption plays an important role in farmers' daily life, especially in developing countries or regions. Here, we review the evolution of the rural household energy consumption structure in northern China from 1996 to 2005. Studies indicate that the proportion of straw, firewood, and coal consumption in total energy consumption have remained at 88.8–91.0%, whereas the proportion of high-quality commercial energy and modern renewable energy is still very low. The main challenges for the sustainable development of rural household energy supply are an unreasonable energy consumption structure, low-energy efficiency, serious environmental degradation, a large gap in energy supply among regions, and difficulty in developing renewable energy. We suggest some countermeasures to overcome the obstacles involved in the sustainable development of rural household energy in northern China, from energy sources to sociopolitical policies.

Keywords: Household energy consumption; Northern China; Rural areas; Renewable energy; Sustainable development

Contents

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1. Introduction

Rural household energy consumption structure is an important index reflecting rural economics and the living standards of farmers. Over the long term, rural household energy consumption in China has mainly depended on traditional biomass energy, such as straw and firewood, which has low-energy efficiency, negative environmental effects, and can cause unsanitary conditions both indoors and outdoors [1–3]. With the development of the social economy, the improvement of farmer living standards, and strengthened awareness of environmental protection, the energy consumption structure has been gradually ameliorated; the proportion of commercial energy consumption increased from 15.7% in 1980 to 45.0% in 2005 [4,5].

Many factors affect the rural household energy structure, including the economy, society, culture, local energy sources, and climate [6,7]. The rural household energy structure is distinct in different regions of China because the country has a complex distribution of physical geography and social economy. In particular, an obvious distinction exists between northern and southern China because of the longer cold season, more fragile environment, and poorer economic status of northern China [8,9], which appears in the greater heating energy consumption and huge potential for increasing energy demands in the future. With the implementation of the development strategies proposed in recent years, i.e., "Building an overall well-off society," "Coordinating urban and rural development and coordinating regional development," "The great development of west China," "Revitalizing the Northeast old industrial base," and especially, "The construction of a new Socialist rural China," rural areas of northern China will have important development opportunities. With development, the rural household energy consumption will change dramatically, and may be a serious challenge to rural energy systems and the environment. Thus, research is needed to understand the evolution of the rural household energy structure and its conflicts with sustainable development in northern China, which are extremely relevant to the balance of energy consumption and supply, rural energy security, and sustainable social, economic, and environmental development throughout China.

2. Description of rural areas in northern China

Here, we consider northern China as northeast, north, and northwest China; southern China is composed of the remaining regions. To simplify this research, the regions are divided into province-level administration areas. Thus, northern China is composed of 14 provinces, autonomous regions or municipality directly under the Central Government: Heilongjiang, Jilin, Liaoning, Beijing, Tianjing, Hebei, Inner Mongolia, Shanxi, Shandong, Lingxia, Shaanxi, Gansu, Qinhai, and Xinjiang (Fig. 1). These regions comprise $5.47 \times 10^6\,km^2$, which covers 57% of the land territory of China. The rural population of northern China was 293 million in 2005, which accounted for 30.89% of the total population. The annual net per capita farm income was 3280 RMB (Chinese Yuan), 180 RMB less than that of southern China in 2005, and a large proportion of the population lived below the poverty line.

Per capita land resources are relatively abundant in northern China, but land is in arid, semiarid, or desert regions. The environment is vulnerable, which is demonstrated, for example, by serious soil erosion, soil desertification and salinization–alkalization, shortages of agricultural water resources, and lowering of groundwater levels. In addition, annual effective cumulative temperature is relatively low; tillage-cropping systems obtain one or two crops per year or three crops every 2 years. Agricultural productivity is relatively low; on average, the production biomass per unit area is lower than that of southern China.

We used statistical figures from the Rural Household Energy Consumption Statistical Yearbook of China (1996–2005) and the Statistical Yearbook of China (1996–2005) [5,10].



Fig. 1. Provinces comprising the main northern regions of China.

Because of the lack of some data for 1997 and the Tibet autonomous region, both were excluded from the statistical analyses.

3. Rural household energy consumption levels and structures in northern China

Rural household energy consumption refers to the total end-use of energy for cooking, lighting, heating, refrigeration, amusement, transportation, and other uses [11]. Energy sources include not only commercial and traditional renewable energy sources, but also renewable energy sources produced using modern technology. Table 1 shows the evolution of the rural household energy consumption structure in northern China from 1996 to 2005.

The proportion of traditional biomass energy consumption to total energy consumption decreased from 56.0% in 1996 to 47.2% in 2005, whereas that of commercial energy consumption increased from 43.8 to 52.5%. Although the proportion of traditional biomass energy consumption has declined, its quantity has increased continuously from 67.8 million ton of standard coal equivalent (Mtce) in 1996 to 85.5 Mtce in 2005 because of a growing population and increasing energy demand. For commercial energy sources, coal showed the largest net increment because heating energy consumption increased rapidly; consumption of oil products, liquefied petroleum gases (LPG) and electricity also increased.

In addition, modern renewable energy has developed quickly in northern China in recent years. For example, the area used to obtain solar energy increased from $9.73 \times 10^6\,m^2$ in 1996 to $57.40 \times 10^6\,m^2$ in 2005. Energy-saving measures, such as energy-saving stoves and kangs, traditional brick sleeping platforms, have achieved great progress too (Table 2). Both of these have played important roles in ameliorating the rural household energy supply and improving energy efficiency in certain areas, especially in the northwest. On the whole, the energy consumption structure was steadily ameliorating (Fig. 2), which was the result of the pursuit of comfort, convenience, as well as sanitary conditions.

Although economic conditions are relatively poor in northern China, the effective per capita heat demand is greater than that in southern China because of the colder climate [7].

Table 1
Rural household energy consumption ($\times 10^4$ tce) in northern China (1996–2005)

Year	Total	Straw	Firewood	Coal	Electricity	Oil products	Biogas	LPG	Natural gas	Coal gas
1996	12,110.25	5107.15	1676.82	4172.88	948.45	118.23	18.53	62.57	1.67	3.95
1997	–	–	–	–	–	–	–	–	–	–
1998	15,202.57	5563.17	1965.81	5964.37	1239.45	230.91	17.67	198.12	16.20	6.85
1999	13,537.94	5599.27	1854.07	4691.03	1037.04	239.80	18.14	88.24	3.49	6.86
2000	14,186.37	5509.74	1993.04	5173.40	1075.06	291.29	20.32	110.43	6.34	6.76
2001	15,542.04	5556.58	2185.42	6275.68	1095.74	316.65	21.73	74.06	8.63	7.54
2002	16,410.74	5800.58	2398.68	6732.68	1008.11	309.65	24.7	116.41	14.53	5.37
2003	17,365.56	6227.61	2518.78	6940.75	1098.99	382.47	36.7	146.68	8.39	5.16
2004	17,502.03	6089.77	2613.30	7068.10	1126.47	413.92	45.96	131.22	8.43	4.82
2005	18,152.12	5975.83	2574.33	7594.38	1172.01	552.34	66.28	160.07	10.98	18.90

Note: (1) Calculated according to rural energy statistical yearbook of China [5], 1996–2005; (2) vacant of some data of 1997.

Table 2
Development of the major modern renewable energy sources and energy-saving measures in rural areas of northern China

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Solar energy ($10^4\,m^2$)	973	–[a]	988	1000.82	1313.5	1338.75	1917.16	3185.91	4995.02	5739.53
Wind power (10^4 kWh)	–[a]	–[a]	–[a]	2118.54	1909.28	2633.32	3099.92	3101.44	2993.23	3131.67
Amounts of straw gasification stations	–[a]	–[a]	158	200	284	289	313	337	341	367
Energy-saving stoves[b] (10^4 users)	5127.29	5308.29	5441.78	5599.81	5640.73	5691.21	5707.23	5738.59	5758.29	5782.97
Energy-saving kangs[b] (10^4 users)	1569.48	1607.63	1677.59	1754.81	1813.45	1861.44	1892.35	1901.05	1923.09	1942.44

[a]Statistics on the use of solar energy in 1997, straw gasification stations during 1996–1997 and wind power during 1996–1998 were scarce.

[b]Energy-saving stoves and energy-saving kangs include modern and older forms.

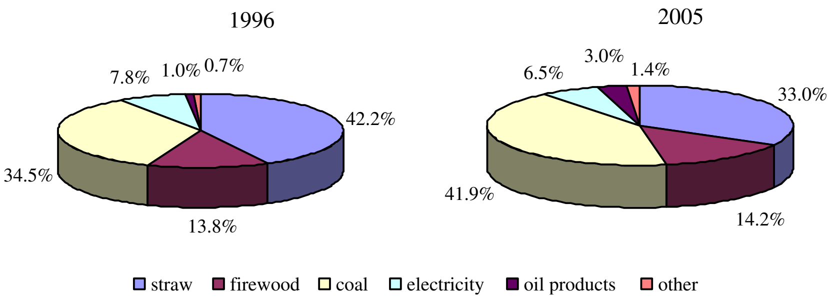


Fig. 2. Rural household energy consumption structure in northern China. *Note*: "Other" includes biogas, liquefied petroleum gases (LPG), natural gas, and coal gas, but not solar energy and wind power, which are included separately in Table 2.

In addition, the annual rural household per capita energy consumption is actual much larger than that in southern China (Table 3). With the improvement of farmers' living standards, per capita household energy consumption quickly increased from 422.23 kg of standard coal equivalent (kgce) in 1996 to 620.56 kgce in 2005.

4. Conflicts of rural household energy consumption with sustainable development in northern China

The amelioration of the rural household energy consumption structure and the development of renewable energy have stimulated regional sustainable development in terms of energy, societal needs, the economy, and the environment, but household energy is still confronted by challenges in sustainable development. The main challenges are posed by an unreasonable energy consumption structure, low-energy efficiency, serious ecological

Table 3
Per capita rural household energy consumption (kgce; 1996–2005)

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Northern China	422.23	–	528.79	469.65	490.52	536.43	565.28	596.77	600.24	620.56
Southern China	350.17	–	333.94	345.26	358.23	403.26	450.36	446.20	469.15	466.83
China	372.79	–	398.74	384.24	399.55	444.67	486.13	493.03	509.80	514.32

Note: (1) Calculated according to rural energy statistical yearbook of China [5], statistical yearbook of China [10], 1996–2005; (2) vacant of some data of 1997.

degradation and environment pollution, an imbalance in energy supply and demand, large gaps in energy supplies among regions, and difficulties in developing renewable energy.

4.1. Unreasonable energy consumption structure

China is relatively rich in coal resources, but has insufficient oil and natural gas resources in terms of fossil energy sources. The per capita energy resources of coal, oil and natural gas amount to 57.1%, 10.0% and 5.1% of the mean global level, respectively [12]. The prices of LPG, oil products and natural gas are high relatively and increase quickly. In addition, China coal resources are mainly distributed in northern region. Due to the low payment ability for the household energy consumption in rural areas of northern China, the consumed energy sources mainly depend on straw, firewood and coal, which are free or cheap.

The consumptions of the three low-grade energy sources have always been greater than that of other energy sources in the rural household energy consumption structure of northern China. The proportion of them in the total energy consumption was between 88.8% and 91.0% from 1996 to 2005. Then the consumption of high-grade energy to farmers was little. Per capita electricity, oil products, LPG, and natural gas consumption was 40.19, 18.94, 5.49 and 0.38 kgce, respectively, in 2005, which accounted for 6.48%, 3.05%, 0.88%, and 0.06%, respectively, of per capita rural household energy consumption in northern China. In addition, although modern renewable energy has developed quickly, it still only occupied a very low proportion at present. This conflict between the low payment ability for commercial energy consumption and the high demand for high-grade energy sources is an important barrier in developing an affluent society in rural areas of northern China.

4.2. Low-energy efficiency and serious environmental degradation

The three low-grade energy sources were mainly used for cooking and house heating, and most were burned directly. For cooking, the thermal efficiency of straw and firewood is about 20%, and of coal is 30%, but that of straw and firewood is only about 10% if they are burned in traditional stoves. For heating, the integrated thermal efficiencies of the three energy sources ranged from 40% to 60%, but the efficiency can reach 75% in some new types of energy-saving oven-kangs [13]. However, energy-saving measures for cooking and heating were poor and not widespread, causing lower thermal efficiency on the whole.

The direct burning of straw and firewood usually results in incomplete combustion, which leads to large emissions of CO and other toxic gases. Coal combustion is not only an

important source of CO_2 emissions, but also the main source of increases in SO_2 emissions. Especially during cold periods, household heating rapidly increased the energy consumption density (energy consumption per unit time) and caused excessive emissions of CO_2, SO_2, and solid particles. Many villages in northern China were surrounded by smog at such time. Large-scale, extensive, and inefficient energy consumption of straw, firewood, and coal not only wastes a large amount of energy resources, but also affects rural living quality, health, and has severe negative environmental effects.

In addition, the net primary productivity per unit area is low because of water and thermal resource restrictions, so the potential of biomass for energy use, which is the main source of rural household energy consumption in northern China, is limited. With this limited purchasing power for commercial energy and insufficient natural resources, the only option is for farmers to excessively exploit straw, firewood, and grass as fuels to ensure basic living conditions in some regions. Farmers cannot be blamed for excessive use of biomass resources for their survival. However, if these conditions persist, they will cause serious ecological degradation, such as reducing the soil organic matter content, exacerbating soil erosion, and increasing land desertification, which will then deleteriously affect regional sustainable development as well the ecological conditions that will ultimately harm the entire country.

4.3. Large gaps in energy consumptions among regions

Northern China is a vast territory, and large differences exist in socioeconomic conditions, natural endowments of energy resources, and cultural traditions. A serious imbalance occurs in the energy consumption structure among regions. The main natural, social, and economic conditions in the "Sanbei" (northeast, north, and northwest China) rural areas are summarized in Table 4. Table 5 shows the rural household energy consumption discrepancy in the "Sanbei" regions from 1996 to 2005.

Table 4
Major natural, social, and economic conditions in northern China

Year	Northeast			North China			Northwest		
	Rural population (10^4 people)	Net per capita income (yuan)	Average temperature during the cold period[a] (°C)	Rural population (10^4 people)	Net per capita income (yuan)	Average temperature during the cold period (°C)	Rural population (10^4 people)	Net per capita income (yuan)	Average temperature during the cold period (°C)
1996	5536.35	2154.27	−7.49	16,850.63	2017.77	0.37	6294.37	1176.35	−2.32
1997	5571.70	2274.17	−6.65	16,801.85	2223.70	1.21	6336.64	1294.41	−0.95
1998	5570.95	2420.95	−7.11	16,805.35	2371.65	1.77	6373.56	1457.31	−0.50
1999	5622.10	2328.23	−7.43	16,805.12	2420.16	1.59	6398.32	1445.5	−1.02
2000	5615.93	2201.32	−9.91	16,867.53	2511.29	0.13	6437.85	1483.14	−1.57
2001	5629.19	2369.68	−9.65	16,864.39	2629.64	0.44	6479.80	1551.87	−0.82
2002	5648.50	2520.42	−6.41	16,868.50	2766.19	2.16	6514.10	1656.83	−0.30
2003	5660.60	2689.21	−6.44	16,899.80	2950.90	0.55	6539.00	1767.11	−1.10
2004	5678.20	3128.15	−6.61	16,884.30	3292.59	1.95	6596.10	1951.24	−0.54
2005	5692.30	3424.17	−9.13	16,930.50	3683.14	0.10	6628.60	2127.93	−2.53

Note: Calculated according to statistical yearbook of China [10], 1996–2005.
[a]According to the characteristics of house heating in northern China, the cold period is from November to March.

Table 5
Rural household per capita energy consumption (kgce)

Region	Year	Total	Straw	Firewood	Coal	Electricity	Oil products	Other[a]
Northeast China	1996	586.23	298.38	98.5	130.14	49.73	6.00	3.48
	1997	–	–	–	–	–	–	–
	1998	667.15	319.08	108.39	130.33	90.13	14.43	4.79
	1999	700.75	370.19	111.23	146.94	55.92	13.17	3.30
	2000	689.60	336.77	125.21	161.69	50.83	7.06	8.04
	2001	687.39	340.23	116.62	167.23	51.94	10.60	0.77
	2002	704.29	350.75	113.08	174.90	45.49	11.53	8.54
	2003	739.27	361.01	116.79	187.73	47.42	16.82	9.50
	2004	792.46	374.75	133.54	211.53	47.33	15.41	9.90
	2005	799.76	376.31	130.06	215.99	49.40	18.20	9.80
North China	1996	385.38	164.62	45.58	138.92	28.99	3.68	3.59
	1997	–	–	–	–	–	–	–
	1998	522.60	180.27	57.52	235.67	31.63	6.0	11.51
	1999	444.77	169.79	49.99	180.76	33.33	5.70	5.20
	2000	462.63	167.67	47.92	198.65	34.51	8.64	5.24
	2001	555.20	176.14	64.40	261.61	35.51	11.79	5.75
	2002	562.15	178.44	65.74	264.70	36.25	11.23	5.79
	2003	597.76	189.93	77.02	274.39	36.37	12.75	7.30
	2004	582.66	175.59	73.43	271.59	40.96	14.19	6.90
	2005	610.01	165.95	72.09	298.55	43.04	19.91	10.47
Northwest China	1996	376.64	108.24	57.73	176.59	29.31	3.67	1.10
	1997	–	–	–	–	–	–	–
	1998	424.16	118.62	62.02	200.49	32.29	7.81	2.93
	1999	331.95	103.89	60.73	129.28	25.40	10.94	1.71
	2000	389.91	122.75	74.80	142.07	32.22	16.46	1.61
	2001	356.41	103.52	68.35	142.36	31.56	8.98	1.64
	2002	452.86	124.24	99.95	196.45	21.43	8.47	2.32
	2003	470.84	148.99	85.02	189.79	33.02	10.99	3.03
	2004	479.74	151.18	93.28	194.26	25.20	13.16	2.66
	2005	489.52	154.49	92.54	197.67	24.47	16.84	3.51

Note: (1) Calculated according to Rural energy statistical yearbook of China [5]; statistical yearbook of China [10], 1996–2005; (2) vacant of some data of 1997.

[a]Other includes biogas, LPG, natural gas, and coal gas, but not solar energy and wind power, which are included separately in Table 2.

The northeast region is the coldest in China, and the frozen period lasts for 4–5 months. Heating is vital for survival in winter, and energy consumption for this purpose is the highest end-use energy consumption type, more than that of cooking, amusement, and other uses. The soil of this region is fertile, and the biomass resources are abundant. Heating energy consumption depends mainly on straw, firewood, and coal, and the per capita household energy consumption of this area is the highest in China. The temperature of north China is the highest among those of the ‘‘Sanbei’’ regions (except for Inner Mongolia), so it is least dependent on heating compared to the other two regions. However, it is also a relatively developed area economically, and has large energy sources, mainly coal and straw, so the per capita total energy consumption is still high in pursuit of a comfortable lifestyle. The northwest is the poorest region in China, and is the most

vulnerable ecologically. Natural resources are deficient, and the per capita energy consumption is the lowest of those of the "Sanbei" region, and even lower than that of southern China. The farmers of this area usually excessively exploited natural biomass resources for energy.

4.4. Difficulty in developing modern renewable energy

The exploitation of modern renewable energy is of strategic importance to the sustainable development of rural household energy consumption in northern China. It can not only supply a large amount of energy to rural areas, increase farm income, and improve people's standard of life, but also ameliorate detrimental ecological effects. Abundant renewable energy resources exist, including straw, firewood, solar energy, and wind power. However, the percentages of modern renewable energy consumption relative to the total energy consumption and its exploitation potential were both very low, and direct combustion of straw and firewood was still the main source of renewable energy.

The exploitation and use of modern renewable energy has been affected by the economy, local resources, government policies, technology, and culture. For example, biogas is the main model for the use of modern renewable energy in northern China. A "four-in-one" (sunlight greenhouse, pig house, toilet, and biogas digester) ecological model solved the problem of low temperature, resulting in an increase in farmers' incomes, the supply of high-quality energy, and improved environmental conditions. However, the high cost of this model has slowed the development of biogas digesters, in addition to problems with the scarcity of fermentation feedstock for small-scale breeding farms, space limitations, imperfections in the marketing and servicing of biogas digesters, and alterations in farmers' employment patterns. Straw gasification for cooking, heating, or power is a research direction for biomass energy, but the limitations of capital input, management, product costs, and technology make its development difficult in the short term. Other modern biomass energy sources, solar energy, and wind power, face similar challenges.

5. Countermeasures for rural household energy sustainable development in northern China

Meeting the energy demands to support people's livelihoods and optimizing the household energy consumption structure are vital to the regional development of society, the economy, and the environment. In the context of the shortage of per capita energy resources, huge per capita household energy demand, low payment ability, and vulnerable environment in northern China, it is important to determine methods of rural household energy sustainable development in northern China to build an affluent society as a whole. The following aspects should be emphasized.

5.1. Improving energy efficiency

Through over 30 years of comprehensive rural energy development, the number of households using energy-saving stoves reached 57.83 million in 2005. However, the average thermal efficiency of cooking stoves is about 20%, which is lower than the national standard of 30% and much lower than the 45% of some improved high-efficiency firewood stoves. Improving the integrated thermal efficiency of heating is also an important breakthrough for saving energy in northern rural areas. Currently, heating is mainly

provided by kangs and household heating systems in rural areas. A large gap exists in the thermal efficiency of common kangs and the advanced shelf preinstalled kang-linked stoves of which the efficiency of the latter may exceed 75%. In addition, an obvious discrepancy occurs in the thermal efficiency of stoves supplying household heating. One study showed that the heating energy consumption per building area in a cold period was about 30.7 kgce in China, which was about three times higher than that in developed countries with similar climates [14]. Therefore, it is important to research and distribute advanced energy-saving stoves, kangs, and heating systems for cooking and heating. For the sustainable development of rural household energy in northern China, it is necessary to first improve energy efficiency.

5.2. *Increasing farmers' income and optimizing the structure of energy consumption*

The development of rural economy and the energy market have been very important for optimizing the structure of energy consumption in northern rural areas since the enactment of the open and reform policy in China. However, the consumed commercial energy source was mainly coal, with some oil and gas, the amount of electricity was slowly increased in the rural market because a large number of farmers were still relatively poor and had low payment ability for household energy consumption. Thus, it is necessary to increase farmers' income to increase the proportion of high-quality commercial energy to the total household energy consumption for fulfilling the demands for comfortable, convenient, and sanitary living conditions.

Considering the merits of renewable energy, the proportion of its use in rural energy consumption should be increased. Renewable energy in rural households is mainly obtained from traditional biomass energy, whereas the amount obtained from modern biomass energy, solar energy, and wind power is small. Therefore, it is important to increase use of these high-quality renewable energy sources and decrease the proportion of traditional biomass energy used. In addition, it should note that increase sustainable and cheap renewable energy consumption (e.g., by planting firewood forests and building solar homes) of poor regions that have deficient natural energy resources in order to ensure the secure supply of household energy consumption.

5.3. *Active and cautious development of renewable energy*

To meet the demands of rural household energy, both the market supply of commercial energy and local renewable energy should be used. Northern China has abundant renewable energy resources. In addition, vast tracts of unproductive agricultural land exist, such as saline–alkaline lands, poor soils, desertified soils, and lands that are no longer tilled, which are suitable for energy plants. Extensive research has been conducted on renewable energy in northern China, resulting in some advanced and profitable technologies such as the "four-in-one" model, 1–5 MW-scale decentralized gasification and power generation systems [15], and solar water heaters. However, the proportion of high-quality renewable energy obtained using modern technologies is still very low in northern China because of economic and management restrictions. The development of advanced technologies should be stimulated via legislation, credit, subsidies, and market regulations. In addition, attention should focus on the research and testing of new but

promising technologies. In other words, we should build a social and political environment that promotes the development of high-quality renewable energy.

Renewable resources should not be exploited randomly, but rather measures should be adjusted to local conditions and practices during the development of renewable energy. For example, the sustainable development of household biogas digesters depends on animal waste. However, the number of small-scale animal-breeding farmers is decreasing and intensive livestock farming is increasing in northern China; therefore, large, medium, and small-scale biogas projects should be developed actively according to farm scale, rather than constructing excessive numbers of household biogas digesters. Furthermore, the direction of development projects is influenced by the scale of farming practices and the physical space constraints in rural areas of northern China.

5.4. *Protecting the environment*

The direct combustion of straw, firewood, and coal for cooking and heating in rural areas is the main source of airborne gaseous pollutants and solid particulates, which are constantly increasing. In northern China, CO_2 emissions from the direct combustion of straw, firewood, and coal were 173.7×10^6, 64.7×10^6, and 158.2×10^6 ton, respectively, and SO_2 emissions from the combustion of coal were 1.43×10^6 ton in 2005 [16]. To reduce pollutant emissions, the amount of direct burning should be reduced and replaced by clean and high-efficiency end-use energy types using appropriate technologies. The over-exploitation of biomass resources will not only reduce soil organic matter contents, but also exacerbate land desertification, soil erosion, declines in biodiversity, and other types of ecological degradation [17]. This trend is more obvious in northern China because of its vulnerable ecological environment. Therefore, amendments of crop residue should be ensured before using straw as energy, and the amount of firewood and grass exploited should remain within the natural carrying capacity.

5.5. *Emphasizing rural household energy development in the northwest*

The challenges in developing rural household energy in the northwest are the most complicated and serious in northern China and in the whole of China. However, the northwest is a major ecological defense barrier for the rest of China, and its ecological security is vital to the sustainable development of the country. Serious ecological degradation has resulted from the overexploitation of natural biomass resources because of a shortage of energy sources to support rural livelihoods. Therefore, finding a solution to the supply of rural household energy in the northwest must be a priority. A stable supply of energy will promote the sustainable development of the northwest and strengthen the ecological security of China. Wind power, solar energy, and the plentiful unused lands should be fully exploited in the development of rural household energy sources in this region.

5.6. *Other measures*

In addition to the above measures, a good external environment in terms of policies, regulations, and finances should be created to accelerate the sustainable development of rural household energy. The rural commercial energy market is undeveloped in the energy

supply structure of China. In addition, the modern biomass energy, wind power, and solar energy industries are presently weak [18]. Commercial energy supply in rural markets should be increased through large-scale adjustments and controls. Moreover, the costs of energy products do not account for environmental costs, which would affect the expansion of modern renewable energy and energy-saving measures. Powerful supporting policies are important for the development of weak industries. The environmental effects of energy products should be assigned monetary values and the products should then be reappraised. Furthermore, renewable energy is a new and promising green industry requiring a large amount of investment and technology; all levels of government should create conditions to promote modern renewable energy industries, via credits, finances, revenues, and policies.

6. Conclusions

The structure of household energy consumption has been somewhat ameliorated and the proportion of commercial energy consumption has been increased 8.7% in rural areas of northern China from 1996 to 2005. Per capita annual household energy consumption quickly increased from 422.23 to 620.56 kgce of the same time. However, the structure of rural energy consumption has not been radically improved; the main energy consumption consists of extensive use of low-efficiency straw, firewood, and coal combustion. The proportions of these three energy types in the total energy consumption have remained at very high levels. The high-quality commercial energy and modern renewable energy sources only occupied a low proportion because of low payment ability and the limited economic benefits.

Economic conditions are relatively poor in northern China, but its per capita energy consumption to support human livelihoods is greater than that in southern China because it has a long cold season and more energy is required for heating. The ecological environment of northern China is fragile, especially in northwest China. Excessive exploitation of natural biomass and the current types of rural household energy consumption have caused the deterioration of the ecological environment and have badly constrained regional sustainable development in terms of energy, societal needs, the economy, and the environment. To solve the above challenges, we should focus more on improving energy efficiency, increasing farmers' income, optimizing the structure of energy consumption, actively and cautiously developing renewable energy, protecting the environment during energy source exploitation and use, and emphasizing rural household energy development in the northwest. In addition, a good external environment in terms of polices, regulations, finances, and revenues should be created to benefit the development of household energy use in rural areas of northern China.

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